# IEC 63145-22-20

Edition 1.0    2024-02

# INTERNATIONAL STANDARD

colour
inside

**Eyewear display –**
**Part 22-20: Specific measurement methods for AR type – Image quality**

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INTERNATIONAL
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## CONTENTS

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**EYEWEAR DISPLAY –**

**Part 22-20: Specific measurement methods for AR type – Image quality**

FOREWORD

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The text of this International Standard is based on the following documents:

| Draft | Report on voting |
|---|---|
| 110/1580/FDIS | 110/1599/RVD |

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 63145 series, published under the general title *Eyewear display*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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## EYEWEAR DISPLAY –

## Part 22-20: Specific measurement methods for AR type – Image quality

## 1 Scope

This part of IEC 63145 specifies the standard measuring conditions and measurement methods for determining the image quality of augmented reality (AR) type eyewear displays. This document applies to see-through type (AR glasses) eyewear displays using virtual image optics.

See-through type displays (VR glasses), contact lens-type displays, and retina direct projection displays are out of the scope of this document.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 63145-1-2, *Eyewear display – Part 1-2: Generic – Terminology*

IEC 63145-20-10:2019, *Eyewear display – Part 20-10: Fundamental measurements – Optical properties*

IEC 63145-20-20:2019, *Eyewear display– Part 20-20: Fundamental measurements – Image quality*

ISO 9241-302, *Ergonomics of human-system interaction – Part 302: Terminology for electronic visual displays*

ISO/CIE 11664-1, *Colorimetry – Part 1: CIE standard colorimetric observers*

ISO/CIE 11664-5, *Colorimetry – Part 5: CIE 1976 L*u*v* colour space and u', v' uniform chromaticity scale diagram*

CIE 015:2018, *Colorimetry*

## 3 Terms, definitions, abbreviated terms and letter symbols

### 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 63145-1-2, IEC 63145-20-10, IEC 63145-20-20 and ISO 9241-302 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

NOTE 1    Terms related to eyewear displays will be defined in specific projects.

NOTE 2    Additional terms can be found in IEC TR 63145-1-1 [1][1].

## 3.2    Abbreviated terms

2D          two-dimensional

AR          augmented reality

CIE         Commission Internationale de l'Eclairage (International Commission on Illumination)

CPD        cycles per degree

DUT        device under test

FOV        field of view

LMD        light measuring device

ppd         pixel per degree

## 3.3    Letter symbols (quantity symbols or unit symbols)

The letter symbols for eyewear display are shown in Table 1.

**Table 1 – Letter symbols (quantity symbols or unit symbols)**

| Definition | Symbol |
|---|---|
| Measuring point of virtual image ($i$ = 0 at the centre) | $P_i$ |
| Measuring point of real scene target ($i$ = 0 at the centre) | $B_i$ |
| Luminance of a position $(x, y, z)$ in a direction $(\alpha, \Psi)$ on the eyewear display | $L_v(x, y, z, \alpha, \Psi)$ (cd m$^{-2}$) |
| Spectral radiance of the virtual image at $P_i$ point under ambient illumination | $L_{Amb}(\lambda, i)$ (W sr$^{-1}$ m$^{-2}$ nm$^{-1}$) |
| Spectral radiance of the virtual image at $P_i$ point under dark background | $L_D(\lambda, i)$ (W sr$^{-1}$ m$^{-2}$ nm$^{-1}$) |
| Average luminance (spatial) | $L_{av}$ (cd m$^{-2}$) |
| CIE 1931 chromaticity coordinates at $P_i$ | $x_i, y_i$ |
| Chromaticity gamut area | $A_{xy}$ |
| CIE 1976 chromaticity coordinates at $P_i$ | $u'_i, v'_i$ |
| Chromaticity deviation | $\Delta u'v'$ |
| Luminance ratio | $C_{vb}$ |
| Ambient contrast ratio | $CR_A$ |
| Spectral transmittance of the DUT at $P_i$ point | $T(\lambda, i)$ |
| Spectral radiance of the illumination background | $L_s(\lambda)$ (W sr$^{-1}$ m$^{-2}$ nm$^{-1}$) |
| CIE standard spectral luminous efficiency for photopic vision | $V(\lambda)$ |
| Wavelength interval | $\Delta\lambda$ (nm) |

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1    Numbers in square brackets refer to the Bibliography.

# 4 Standard measuring conditions

## 4.1 Standard environment conditions

Unless otherwise specified, all tests and measurements for eyewear displays shall be carried out after sufficient warm-up time for illumination sources and the DUT (see 4.3), under the following standard environmental conditions:

- temperature:              22°C to 28°C,
- relative humidity:         25 % to 85 %,
- atmospheric pressure:   86 kPa to 106 kPa.

When different environmental conditions are used, they shall be reported in detail in the specification.

## 4.2 Power supply

In order to stabilize the performance of the DUT, the power supply for driving the DUT shall be adjusted in accordance with the specification of the DUT.

## 4.3 Warm-up time

The optical performances of the DUT are affected by the transient temperature behaviour of the device. It takes a certain time for the DUT and LMD until their performances reach the steady-state. All measuring conditions shall be kept constant during the measurements. If the luminance output is not within a ±3 % variation, it shall be reported.

## 4.4 Dark room condition

The luminance contribution from the background of the test room reflected off the measurement space shall be less than 1/20 of the minimum luminance output from the DUT. If this condition is not satisfied, then background luminance can be subtracted, and it shall be reported.

# 5 Measurement systems

## 5.1 Standard coordinate system

A spherical coordinate system ($\alpha$ and $\Psi$ angles) shall be used in the measurements, as shown in Figure 1. The polar axis is vertically oriented. The angles measured in the vertical half-planes of data are elevation angles, denoted as $\alpha$, and the horizontal angles to the half-plane are azimuth angles, denoted as $\Psi$. A geographic coordinate chart can be used to express the spherical coordinates of the virtual image produced by the DUT. Refer to IEC 63145-20-10:2019, Clause 5.

The origin direction ($\alpha = 0$, $\Psi = 0$) of the spherical coordinate system is coincident with the optical axis of the DUT. When performing measurements simulating eye rotation, the centre of the spherical coordinate system should be 10 mm behind the LMD entrance pupil.

To indicate the positional relationship between the designed eye point of the DUT and the entrance pupil of the human eye or LMD, a Cartesian coordinates system ($x, y, z$) is used, as shown in Figure 2.

The origin of the Cartesian coordinates system should be located at the centre of the entrance pupil of the eye, which is matched with the eye point of the DUT. The manufacturer or supplier should provide the eye point position.
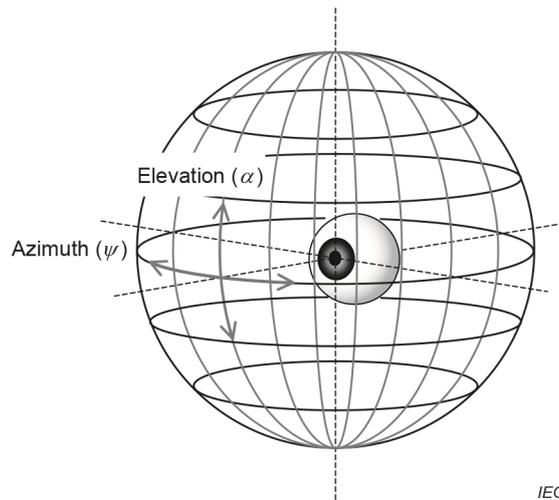
**Figure 1 – Spherical coordinate system**
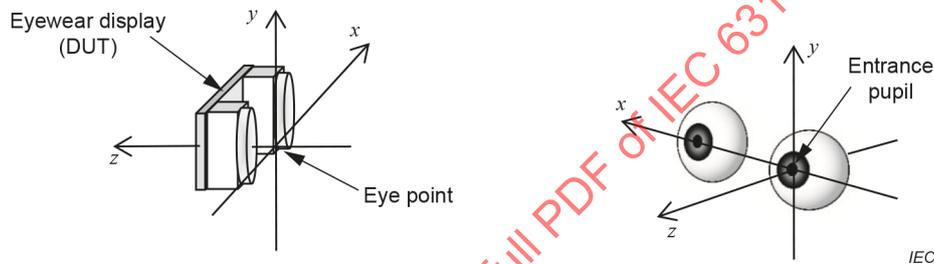


NOTE   The drawing shows an example of adjusting the eye pupil to the eye point, which is the origin position.

**Figure 2 – Three-dimensional Cartesian coordinate system**

## 5.2    Measurement equipment

### 5.2.1    General

The configurations and operating conditions of the equipment should comply with the structures specified in each item. To ensure repeatable measurements, the requirements shall comply with IEC 63145-20-10. Otherwise, the differences shall be noted in the report.

### 5.2.2    Light measuring device (LMD)

The LMDs shall refer to the requirements in IEC 63145-20-10 unless otherwise specified in each item.

### 5.2.3    Stage conditions

#### 5.2.3.1    General

The stage shall be used to realize the coordinate system specified in 5.1. The stage shall be constructed with the equivalent of a biaxial goniometer and an orthogonal three-axis translation stage.

**5.2.3.2    Goniometer**

Refer IEC 63145-20-10:2019, 5.2.2.2.

A biaxial goniometer shall be assembled to be capable of measuring azimuth (horizontal) and elevation (vertical) angles in the spherical coordinate system as in Figure 1. Examples of the five-axis stage are shown in IEC 63145-20-10:2019, Figure 4. The angular accuracy should be no less than 0,1°. The goniometer can be pivoted at the centre of the entrance pupil of the LMD, or 10 mm behind the entrance pupil, or both, to simulate eye rotation.

**5.2.3.3    Translation stage**

Refer to IEC 63145-20-10:2019, 5.2.2.3.

An orthogonal three-axis translation stage assembles with an adequate range to cover the measuring distance such as the eye-box volume, and if necessary to cover the interpupillary distance for binocular DUTs, as in the example shown in IEC 63145-20-10:2019, Figure 4. The translation accuracy should be no less than 0,05 mm.

**5.2.4    Setup conditions**

Refer to IEC 63145-20-10:2019. 5.2.3.

The DUT shall be mounted on a stable platform to ensure image stability. The LMD position relative to the DUT shall be moved by using a five-axis system (a biaxial goniometer and three-axis orthogonally translation stage). The LMD installed on the biaxial goniometer, as in the example in IEC 63145-20-10:2019, Figure 4 a), shall be consistently pivoted around its pupil centre (eye point) or about the centre of the eyeball rotation for each set of measurements. The optical axis of the DUT, which is decided by a manufacturer or a supplier, shall be adjusted to the optical axis of the LMD and shall be aligned with the $z$-axis of the orthogonal three-axis translation stage. The aspect of the virtual image of the DUT shall be adjusted to the $x$- and $y$-axes of the orthogonal three-axis translation stage.

For the measuring condition from an anterior view, when the DUT does not suppose the change of gaze angle (eye rotation), the origin of a biaxial goniometer shall be assumed as the entrance pupil of the eye (i.e. eye point of the DUT), not the rotation centre of the eyeball (eye movement). When the origin of the biaxial goniometer does not match the eye point, the coordinate correction shall be required, and it shall be reported. When the DUT supposes the change of the gaze angle, detailed information such as the position of the rotation centre shall be specified by the manufacturer or the supplier and reported.

For the measurement of a see-through real scene, the real scene pattern target shall be set at a distance specified by the manufacturer or supplier, and the optical axis of the LMD shall be adjusted to be consistent with the normal line of the pattern target. The DUT installed on the biaxial goniometer as in the example in IEC 63145-20-10:2019, Figure 4 b), can be pivoted around its eye point (pupil rotation) or about the centre of the eye.

# 6    Background and see-through real scene conditions

## 6.1    General

The virtual image quality of AR type eyewear displays will be significantly affected by the background and see-through real scene conditions. The test background and see-through real scene shall comply with the specified luminance level and illuminant conditions in each item, as well as the distance, which are provided by the manufacturer or the supplier.

## 6.2 Ambient background

Ambient background is a background condition to test the characteristics of the DUT under ambient illumination conditions. Figure 3 is an example of the ambient background setup. Uniform spherical illumination using a hemisphere, or a full integrating sphere with a stable light source, is used to generate the full-field background illumination. The solid angle of the full field shall be no less than the see-through FOV of the DUT. The luminance variation within the full field should be less than 2 % as measured by tilting the LMD over the full field. If this is not achieved, the background luminance should be corrected in the measurement at each direction, and the correction method and corrected variation value should be reported.
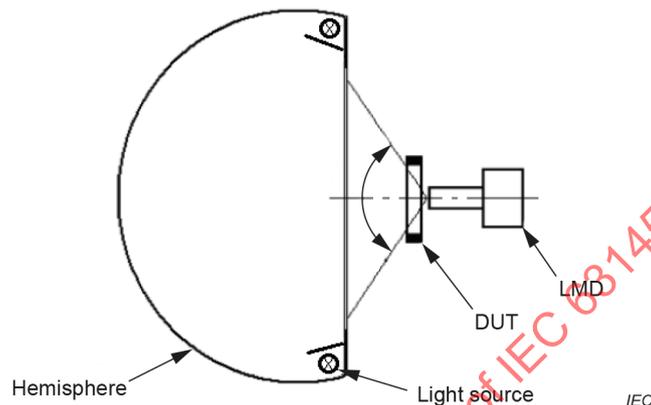


**Figure 3 – Example of the ambient background**

The relative spectral distribution of the light source shall comply with CIE illuminants, such as CIE Illuminant A, D50, or D65 as in CIE 015, and be reported. However, when a spectroradiometer is applied, the source can be a continuous smooth spectral power distribution of at least 380 nm to 780 nm, and the results can be obtained by calculating with the above CIE illuminants. The background luminance and its applied illuminant shall be specified by the manufacturer or the supplier. Some example cases of background luminance include indoor lighting (30 cd m$^{-2}$ to 500 cd m$^{-2}$), outdoor sunlight (2 000 cd m$^{-2}$ for overcast sky, and 15 000 cd m$^{-2}$ for clear sky), but the application cases are flexible, and not specified in this document. The light from the surrounding scene consists of different components in actual use cases. In this document, ambient illumination with a diffuse profile is considered [2] to [4].

## 6.3 Raster pattern (or grille pattern) targets

The raster pattern targets are used to determine the Michelson contrast of the real scene for AR type eyewear displays at a direction ($\alpha$, $\Psi$) in front of the viewer. The pattern can be implemented by setting a horizontal (or vertical, or both) raster pattern plate in front of the light output port of a uniform source, such as an integrating sphere or hemisphere or generated by a non-transparent display. The raster pattern plate can be composed of black (non-transparent) and transparent stripes with the same width, and the angular frequency ($f_{CPD}$) can be calculated from the black and white line-pairs of the raster pattern at a given distance which should be far enough from the DUT (e.g., more than 20 times of the measured pattern dimension) as shown in the example in Figure 4. The angular resolution shall be specified by the manufacturer or the supplier, for example of 60 cycles per degree, 30 cycles per degree, 15 cycles per degree, and 10 cycles per degree at the viewing location (eye point). The relative spectral distribution and luminance of the light output port shall be specified by the manufacturer or the supplier or as in 6.2.

Measuring direction $(\alpha, \psi)$

Optical axis of DUT

LMD

DUT

Raster pattern plate

Uniform source (integrating sphere)
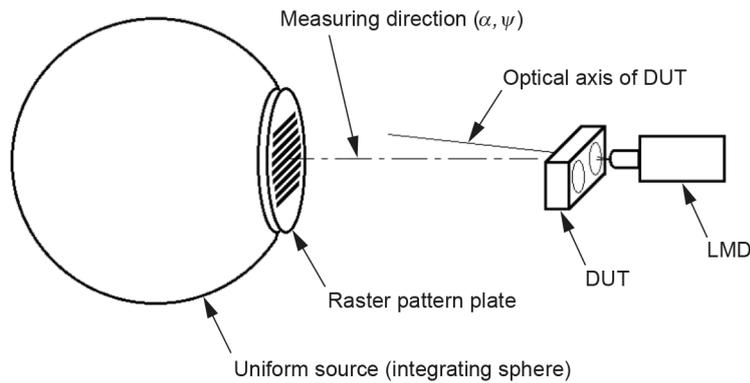
IEC

**Figure 4 – Example of the setting for a raster pattern target**

NOTE   Display pixelation can cause non-uniformities within the grille. These variations will be smoothed out in the analysis.

## 6.4 Crosshair pattern target

The crosshair pattern target shall be used to test the geometric distortions of the real scene through AR type eyewear displays as well as the positioning accuracy of the virtual image to align with the real scene point at a direction $(\alpha, \Psi)$. The pattern is composed of a bright crosshair (cross) sign with a width provided by the manufacturer or the supplier, which can be achieved by setting a transparent cross plate in front of the light output port of a uniform source, as shown in the example in Figure 5.

NOTE 1   Crosshair pattern target is a transparent cross sign on a black plate target (made of metal or glass). It is commonly used in orientation and target alignment. Its width is considered relative to the test distance, and its line width is at a given distance, which is close to the minimum resolvable line width of the virtual image.

NOTE 2   In some cases, a crosshatch pattern with a width given by the manufacturer or the supplier can be applied.

Measuring direction $(\alpha, \psi)$

Optical axis of DUT

LMD

DUT

Crosshair pattern plate

Uniform source (integrating sphere)
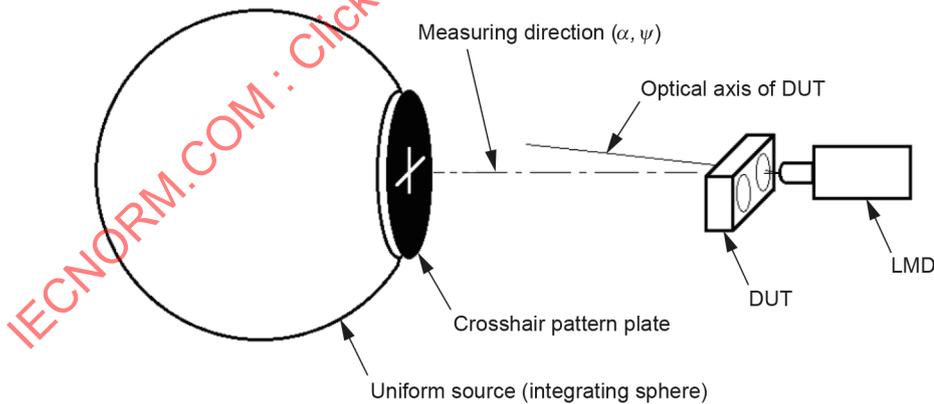
IEC

**Figure 5 – Example of the setting for a crosshair pattern target**

## 7 Test patterns of the virtual image

### 7.1 General

The following test patterns shall be specified by the manufacturer or the supplier, and the applied test pattern shall be noted in the report. When other test patterns are applied, they shall be noted in the report.

NOTE  Unlike a flat panel display with clearly visible edges display, the boundary of the display area is not clear, and the choice of test pattern can affect the measurement results.

### 7.2 Checkerboard pattern

Refer to IEC 63145-20-10:2019, 5.3.2.

### 7.3 Solid colour patterns

Refer to IEC 63145-20-10:2019, 5.3.3.

### 7.4 Raster patterns

Refer to IEC 63145-20-20:2019, 5.3.4.

### 7.5 Measuring points

Refer to IEC 63145-20-20:2019, 5.4.

## 8 Measurement methods

### 8.1 Preparation

AR type eyewear displays to be measured (DUT) shall be placed in the measurement arrangement specified in Clause 5. The eye point of the DUT shall be specified by the manufacturer or supplier (see IEC 63145-20-10:2019, Annex B). The eye point and the entrance pupil of the LMD shall match the origin position ($x = 0$, $y = 0$, $z = 0$, $\alpha = 0$, $\Psi = 0$).

The DUT adjustable conditions which are related to optical properties shall be specified by the manufacturer or supplier. Some DUTs use image processing, and if a setting for the image processing is adjustable, the default setting specified by the manufacturer or supplier shall be applied and reported.

The entrance pupil of the LMD shall be centred to be consistent with the designed eye point of the DUT at the origin position ($x = 0$, $y = 0$, $z = 0$). An alignment pattern with a crosshair at the centre position can be used for adjustment of the origin ($\alpha = 0$, $\Psi = 0$) of the LMD.

NOTE 1  In case the pivoting point of the LMD is 10 mm behind the entrance pupil, this pivoting point can be used, instead of the entrance pupil, to match the origin position of the measurement.

For the measurement of virtual images, a raster pattern target, specified in 7.4 with a high resolution can be provided by the manufacturer or supplier, and can be applied to adjust the virtual image focus.

For the measurement of real scenes, a raster pattern target as specified in 6.3 with a high angular resolution which depends on the distance of the pattern target and provided by the manufacturer or supplier, can be applied to the adjustment of the real scene focus.

The optical quantities of the LMD, such as luminance and spectral radiance, shall be calibrated against traceable standards under the same conditions (for example entrance pupil size and measurement field angle, and focus distance in some structures).

The optical quantities at different measuring points (directions) shall be measured at the steady-state after the required time specified in 4.3.

NOTE 2   Some eyewear displays have eye-tracking capabilities for optimizing the image. The gaze direction of the LMD will agree with the gaze direction as detected by the DUT for a true eye, if applicable.

## 8.2   Luminous transmittance and spectral transmittance with an ambient diffuse illumination

### 8.2.1   General

The purpose of this method is to measure the spectral transmittance of an AR type eyewear display in given directions, to determine the virtual image quality under the ambient diffuse illumination conditions, and the see-through real scene quality.

### 8.2.2   Measuring conditions

a) Setup: an ambient background shall be applied as specified in 6.2. The optical axis of the DUT is set at the normal of the output port. The LMD shall be installed to match the entrance pupil of the LMD with the DUT's eye point and the optical axis between the LMD and DUT.

b) Light measuring devices (LMDs): a spectral radiance meter shall be applied as specified in 5.2.2.

c) Test patterns: the full screen solid colour patterns as specified in 7.3 shall be applied.

d) Measuring points: the points (directions) to be measured on the virtual image as specified in IEC 61345-20-20:2019, 5.4, or the specified points (directions) on the real scene in each point to be measured. The LMD is adjusted to focus on the measuring points.

### 8.2.3   Measuring procedures

The spectral transmittance of the DUT at the measuring point, such as the measuring point $P_i$ ($i$ = 0 to 8) of the virtual image specified in IEC 63145-20-20:2019, 5.4, shall be measured as follows:

a) The LMD is focused on the measuring point.

b) In a dark background, the DUT is applied with the full screen patterns, such as black and white patterns, then the spectral radiance of the virtual image at point $P_i$, $L_{D,K}(\lambda, i)$ and $L_{D,W}(\lambda, i)$, is measured, respectively.

c) Turn on the illuminating source of the integrating sphere until it is stable in the light output (luminance variation less than 1 %). Apply full screen patterns, such as black and white patterns, to measure the spectral radiance at point $P_i$, $L_{Amb,K}(\lambda, i)$ and $L_{Amb,W}(\lambda, i)$, respectively, for the combination of the virtual image and the background illumination.

d) Remove the DUT, and then measure the spectral radiance of the output port of the illuminating sphere, $L_0(\lambda, i)$.

e) For a binocular AR type eyewear display, repeat steps a) to c) to determine the spectral transmittance of another ocular, if applicable.

### 8.2.4   Calculation

The spectral transmittance at the point $P_i$ ($i$ = 0 to 8) can be calculated as follows.

An example of the DUT with the white pattern is as follows:

$$T_W(\lambda, i) = \frac{L_{Amb,W}(\lambda, i) - L_{D,W}(\lambda, i)}{L_0(\lambda, i)} \tag{1}$$

where

$T_W(\lambda, i)$      is the spectral transmittance at point $P_i$ ($i$ = 0 to 8) for the DUT with the white pattern;

$L_{Amb,W}(\lambda, i)$   is the spectral radiance at point $P_i$ ($i$ = 0 to 8) under the diffuse illumination for the DUT with the white pattern;

$L_{D,W}(\lambda, i)$    is the spectral radiance at point $P_i$ ($i$ = 0 to 8) under the dark background for the DUT with the white pattern;

$L_0(\lambda, i)$      is the spectral radiance of the output port of the illuminating sphere.

The luminous transmittance, $T_W(i)$ ($i$ = 0 to 8), of the DUT under the diffuse illumination can be calculated as follows:

$$T_W(i) = \frac{\sum_{380}^{780} S(\lambda) T_W(\lambda, i) V(\lambda) \Delta\lambda}{\sum_{380}^{780} S(\lambda) V(\lambda) \Delta\lambda} \tag{2}$$

where

$S(\lambda)$    is the relative spectral radiance of the diffuse illumination (see 6.2);

$V(\lambda)$    is the CIE standard spectral luminous efficiency function for photopic vision (see ISO/CIE 23539 [8]);

$\Delta\lambda$    is the spectral interval of the calculation.

An example of the DUT with the black pattern is as follows:

$$T_K(\lambda, i) = \frac{L_{Amb,K}(\lambda, i) - L_{D,K}(\lambda, i)}{L_0(\lambda, i)} \tag{3}$$

where

$T_K(\lambda, i)$      is the spectral transmittance at point $P_i$ ($i$ = 0 to 8) for the DUT with the black pattern;

$L_{Amb,K}(\lambda, i)$   is the spectral radiance at point $P_i$ ($i$ = 0 to 8) under the illumination for the DUT with the black pattern;

$L_{D,K}(\lambda, i)$    is the spectral radiance at point $P_i$ ($i$ = 0 to 8) under the dark background for the DUT with the black pattern.

The luminous transmittance, $T_K(i)$ ($i$ = 0 to 8), of the DUT under the diffuse illumination can be calculated as follows:

$$T_K(i) = \frac{\sum_{380}^{780} S(\lambda) T_K(\lambda, i) V(\lambda) \Delta\lambda}{\sum_{380}^{780} S(\lambda) V(\lambda) \Delta\lambda} \tag{4}$$

NOTE   In many cases, the DUT has substantially the same spectral transmittance, which is independent of the displaying patterns. The measurement can be simplified to display the off-state only.

**8.2.5    Report**

The following items shall be reported:

– diffuse illumination background: luminance level and relative spectral distribution (type of the illuminant);

– measurement locations (directions) and focusing distance of the LMD;

– light output non-uniformity of the integrating sphere;

– luminous transmittance and spectral transmittance of the DUT applied with the white pattern at each point;

– luminous transmittance and spectral transmittance of the DUT applied with the black pattern at each point;

– eye point (eye relief) and the position of the $z$-axis;

– type of LMD and the entrance pupil size;

– correction methods for the measurement, if necessary, for example, the correction of the luminance non-uniformity or the angle shall be applied.

**8.3    Parameters related to virtual images**

**8.3.1    Ambient contrast ratio**

**8.3.1.1    General**

The purpose of this method is to determine the ambient contrast ratio at the centre, sides and corners of the virtual image for an AR type eyewear display by using the checkerboard patterns under an ambient illumination background. The ambient illumination conditions can be provided by the manufacturer or the supplier. If the eyewear display has ambient detection capability for adjusting the luminance level of the virtual image, the ambient detection should be set in accordance with the product specification.

**8.3.1.2    Measuring conditions**

a) The setup and light measuring devices (LMDs) shall be applied as in 8.2.2.

b) Test patterns: the checkerboard patterns with centre white and centre black shall be applied.

c) Measurement locations: nine points as shown in IEC 61345-20-10:2019, 5.4, are applied. $H$ and $V$ represent the horizontal and vertical angles of the FOV for the virtual image.

**8.3.1.3    Procedures**

The spectral transmittance $T_W(\lambda, i)$ of the white blocks and $T_K(\lambda, i)$ of the black blocks at point $P_i$ ($i$ = 0 to 8) for the DUT with checkerboard patterns can be obtained as in 8.2.

In the dark background, apply 5 × 5 checkerboard patterns as shown in IEC 61345-20-10:2019, 5.3.2, with centre white and centre black, respectively, to measure the spectral radiance of the virtual image at point $P_i$ ($i$ = 0 to 8), $L_{D,K}(\lambda, i)$ and $L_{D,W}(\lambda, i)$.

**8.3.1.4    Calculation**

a) Ambient luminance level $L_s$ and relative spectral distribution $S(\lambda)$ of the illumination background defined in 6.2, shall be specified by the manufacturer or supplier.

b)  Ambient contrast ratio of the DUT at point $P_i$ ($i$ = 0 to 8) can be calculated as follows:

$$CR_A(i) = \frac{L_{Amb,W}(i)}{L_{Amb,K}(i)} \tag{5}$$

where

$L_{Amb,K}(i)$ is the luminance at point $P_i$ ($i$ = 0 to 8) under the illumination for the DUT with the black block; it is the total luminance measured from the LMD (both the virtual image and ambient background illumination);

$L_{Amb,W}(i)$ is the luminance at point $P_i$ ($i$ = 0 to 8) under the illumination for the DUT with the white block; it is the total luminance measured from the LMD (both the virtual image and ambient background illumination).

$$L_{Amb,W}(i) = 683 \cdot \sum_{380}^{780} \left( L_{D,W}(\lambda,i) + T_W(\lambda,i) \cdot L_s(\lambda) \right) \cdot V(\lambda) \cdot \Delta\lambda \tag{6}$$

where

$T_W(\lambda, i)$ is the spectral transmittance of the white block;

$L_{D,W}(\lambda, i)$ is the spectral radiance at point $P_i$ ($i$ = 0 to 8) under the dark background for the DUT with the white block;

$L_s(\lambda)$ is the spectral radiance of the specified standard illumination background, given in Formula (7).

$$L_s(\lambda) = \frac{L_s \cdot S(\lambda)}{683 \cdot \sum_{380}^{780} S(\lambda) \cdot V(\lambda) \cdot \Delta\lambda} \tag{7}$$

where

$L_s$ is the ambient luminance of the illumination background (see 6.2).

$$L_{Amb,K}(i) = 683 \cdot \sum_{380}^{780} \left( L_{D,K}(\lambda,i) + T_K(\lambda,i) \cdot L_s(\lambda) \right) \cdot V(\lambda) \cdot \Delta\lambda \tag{8}$$

where

$T_K(\lambda, i)$ is the spectral transmittance of the black block;

$L_{D,K}(\lambda, i)$ is the spectral radiance at point $P_i$ ($i$ = 0 to 8) under the dark background for the DUT with the black block.

Finally, the averaged ambient contrast ratio, $CR_{A,av}$, is given as:

$$CR_{A,av} = \frac{1}{9} \sum_{i=0}^{8} CR_A(i) \tag{9}$$

NOTE   $L_{Amb,W}(i)$ and $L_{Amb,K}(i)$ can be measured directly instead of measuring $L_{D,W}(\lambda, i)$, $L_{D,K}(\lambda, i)$, $T_W(\lambda, i)$ and $T_K(\lambda, i)$, when the specified standard illumination background is applied in the measurement.

### 8.3.1.5    Report

The following items shall be reported:

– ambient illuminating conditions: the luminance level and relative spectral distribution;

– ambient contrast ratio of the DUT at each point;

– ambient contrast ratio at the centre, and averaged ambient contrast ratio;

– test patterns;

– eye point (eye relief), and the position of the $z$-axis;

– type of LMD and the aperture size;

– correction methods for the measurement, if necessary.

### 8.3.2    Ambient chromaticity and chromaticity gamut area

#### 8.3.2.1    General

The purpose of this method is to determine the ambient chromaticity and chromaticity gamut area of the virtual image of an AR type eyewear display at the centre, sides, and corners under an ambient illumination background. The ambient illumination conditions can be provided by the manufacturer or the supplier. For the case when the eyewear display has the ambient detection capability for adjusting the luminance level of the virtual image, the ambient detection should be set in accordance with the product specification.

#### 8.3.2.2    Measuring conditions

a) The setup and light measuring devices (LMDs) shall be applied as in 8.2.2.

b) Test patterns: the full screen solid colour patterns as shown in 7.3.

#### 8.3.2.3    Procedures

a) Align the LMD at the centre of the measurement area $P_i$ ($i$ = 0 to 8) for the centre, sides and corners of the virtual image, as in the measuring points specified in 7.5.

b) The spectral transmittance at the measurement area $P_i$ ($i$ = 0 to 8) for the DUT applied with the full screen solid colour patterns, such as red (R), green (G) and blue (B), respectively, can be obtained as in 8.2, with $T_R(\lambda, i)$, $T_G(\lambda, i)$ and $T_B(\lambda, i)$.

c) In the dark background, apply the full screen solid colour patterns, such as red, green and blue, respectively, to measure the spectral radiance of the virtual image at the area $P_i$ ($i$ = 0 to 8), $L_R(\lambda, i)$, $L_G(\lambda, i)$ and $L_B(\lambda, i)$.

d) Repeat the measurements for the other measuring points.

#### 8.3.2.4    Calculation

a) Ambient illuminating conditions, such as the luminance level $L_s$ and relative spectral distribution $S(\lambda)$ of the illumination background shall be specified by the manufacturer or the supplier. If not, then 150 cd m$^{-2}$ and CIE Illuminant A (2 856 K) for indoor applications, and 1 500 cd m$^{-2}$ and CIE Illuminant D65 (6 500 K) for outdoor applications can be applied.

b) The chromaticity coordinates, $x_Q(i)$, $y_Q(i)$ and $z_Q(i)$ (1 - $x_Q(i)$ - $y_Q(i)$) of the virtual image at the area $P_i$ ($i$ = 0 to 8) for a solid colour pattern "Q" (red, green, and blue) under the ambient illuminating conditions can be calculated as follows:

$$x_Q(i) = \frac{X_Q(i)}{X_Q(i) + Y_Q(i) + Z_Q(i)}$$
$$y_Q(i) = \frac{Y_Q(i)}{X_Q(i) + Y_Q(i) + Z_Q(i)} \tag{10}$$

$$X_{\mathrm{Q}}(i) = 683 \cdot \sum_{380}^{780} \left( L_{\mathrm{Q}}(\lambda,i) + T_{\mathrm{Q}}(\lambda,i) \cdot L_{\mathrm{s}}(\lambda) \right) \cdot \bar{x}(\lambda) \cdot \Delta\lambda$$

$$Y_{\mathrm{Q}}(i) = 683 \cdot \sum_{380}^{780} \left( L_{\mathrm{Q}}(\lambda,i) + T_{\mathrm{Q}}(\lambda,i) \cdot L_{\mathrm{s}}(\lambda) \right) \cdot \bar{y}(\lambda) \cdot \Delta\lambda \qquad (11)$$

$$Z_{\mathrm{Q}}(i) = 683 \cdot \sum_{380}^{780} \left( L_{\mathrm{Q}}(\lambda,i) + T_{\mathrm{Q}}(\lambda,i) \cdot L_{\mathrm{s}}(\lambda) \right) \cdot \bar{z}(\lambda) \cdot \Delta\lambda$$

where

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$     are the CIE colour-matching functions adapted by the CIE in 1931 (see ISO/CIE 11664-1).

In addition,

$$L_{\mathrm{s}}(\lambda) = \frac{L_{\mathrm{s}} \cdot S(\lambda)}{683 \cdot \sum_{380}^{780} S(\lambda) \cdot V(\lambda) \cdot \Delta\lambda} \qquad (12)$$

c) The chromaticity gamut area of the virtual image at the area $P_i$ ($i$ = 0 to 8) for a solid colour pattern "Q" (red, green, and blue) under the ambient illuminating conditions can be calculated from the CIE 1931 chromaticity coordinates $x_{\mathrm{Q}}(i)$, $y_{\mathrm{Q}}(i)$ as follows:

$$A_{xy}(i) = 149{,}6 \left| \left( x_{\mathrm{R}}(i) - x_{\mathrm{B}}(i) \right) \left( y_{\mathrm{G}}(i) - y_{\mathrm{B}}(i) \right) - \left( x_{\mathrm{G}}(i) - x_{\mathrm{B}}(i) \right) \left( y_{\mathrm{R}}(i) - y_{\mathrm{B}}(i) \right) \right| \qquad (13)$$

where

$x_{\mathrm{R}}(i)$, $y_{\mathrm{R}}(i)$     are the chromaticity coordinates for the red pattern at the area $P_i$;

$x_{\mathrm{G}}(i)$, $y_{\mathrm{G}}(i)$     are the chromaticity coordinates for the green pattern at the area $P_i$;

$x_{\mathrm{B}}(i)$, $y_{\mathrm{B}}(i)$     are the chromaticity coordinates for the blue pattern at the area $P_i$;

the subscripts R, G and B are the red, green and blue primaries, respectively.

d) Repeat the calculation of the chromaticity coordinates and chromaticity gamut area for other ambient background illuminating conditions, respectively, if appropriate.

### 8.3.2.5 Report

The following items should be reported:

– ambient illuminating conditions: the luminance level and relative spectral distribution;

– measurement positions;

– test patterns;

– CIE 1931 chromaticity coordinates at the centre, sides and corners under the ambient illuminating conditions;

– chromaticity gamut area at the centre under the ambient illuminating conditions;

– eye point (eye relief) and the position of the $z$-axis;

– type of LMD and the aperture size;

– the correction methods for the measurement, if possible.

### 8.3.3    Static image resolution

#### 8.3.3.1    General

The purpose of this method is to measure the image resolution of the AR type eyewear displays at a given point (direction) by applying static raster patterns. The static image resolution quantifies how close lines in an angular subtense can be to each other and still be visibly resolved in accordance with a luminance modulation threshold which is provided by the manufacturer or supplier. The unit is in cycles (line-pairs) per degree (CPD).

#### 8.3.3.2    Measuring conditions

The following measuring conditions apply.

a)  Setup: as in 6.2. The optical axis of the DUT shall be set at the normal of the output port. The LMD shall be installed to match the DUT, including the entrance pupil of the LMD with the DUT's eye point and the optical axis between the LMD and DUT. The subtending angle of the light output port of the sphere to the entrance pupil of the LMD should be larger than the test FOV of the DUT.

b)  Test patterns: raster pattern targets are applied as in 7.4, where the width of the white and black lines is $n$ (for example, $n$ is from 1 to 5) pixels wide of the DUT.

c)  Light measuring devices (LMDs): a 2D imaging luminance meter can be applied to measure the luminance profile. The measurement direction of the LMD shall be perpendicular to the parallel lines being measured.

   1)  For a spot luminance meter or spectral radiance meter, the number of sampling points crossing each white or black line of the pattern shall be no fewer than 5.

   2)  For a 2D imaging luminance meter, the pixel number of the detector shall be enough. It is recommended that at least 5 detector pixels fill each white or black line at the crossed direction.

d)  Measuring points: the point positions $P_m$ can be at the centre ($m = 0$), the sides ($m = 5, 6, 7, 8$) and the corners ($m = 1, 2, 3, 4$) as shown in IEC 63145-20-10:2019, Figure 6, depending on the product specification.

#### 8.3.3.3    Measurement method

a)  Apply the vertical line patterns with the same width ($n$ pixels，for example, $n$ is from 1 to 5) of the white and black lines at the measuring point $P_m$ ($m = 0$ to 8).

b)  Measure the luminance profiles of the vertical lines as a function of the horizontal position. The sampling direction of the LMD shall be perpendicular to the vertical lines, to determine the black line luminance, $L_K(n)$, and white line luminance, $L_K(n)$.

c)  Repeat the measurement at least three times, and then calculate their average.

d)  Repeat a) to c) for the horizontal lines.

#### 8.3.3.4    Calculation

a)  For the horizontal lines or vertical lines, respectively, calculate the luminance modulation $C_m(n)$ at the measuring point $P_m$ for each pattern with $n$ pixels (for example, $n$ is from 1 to 5) as follows:

$$C_m(n) = \frac{L_W(n) - L_K(n)}{L_W(n) + L_K(n)} \tag{14}$$

where

$C_m(n)$    is the luminance modulation at the measuring point $P_m$ for each pattern with $n$ pixels;

$L_w(n)$    is the average luminance of all centres of white lines ($n = 1$ to 5);

$L_k(n)$    is the average luminance of all centres of black lines ($n = 1$ to 5).

b)  Calculate the effective raster line width

The effective raster line width $n_r$ (pixels) is estimated by linear interpolation to be equal to the luminance modulation threshold $C_T$.

$$n_r = n + \frac{C_T - C_m(n)}{C_m(n+1) + C_m(n)} \tag{15}$$

where

$C_T$    is the luminance modulation threshold for $C_m(n) < C_T < C_m(n+1)$.

c) The luminance modulation threshold $C_T$ can be specified by the manufacturer or the supplier, depending on the applications. An example for $n_r$ calculation is provided in Figure 6, where the measured luminance modulation varies with the line width $n$ (pixels) from pixel 1 to pixel 5.

NOTE    The indicated interpolated value $n_r$ = 1 176 is a theoretical value only that cannot be realized with a display generally unless a special subpixel layout and subpixel rending is applied.
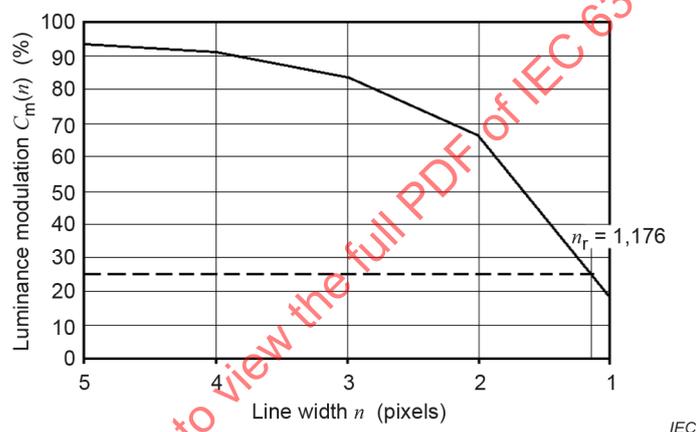


**Figure 6 – Variation of Michelson contrast (i.e. luminance modulation) with line width**

d) Calculate the static image resolution (SIR), $P_{SIR}$ (in the number of resolvable line-pairs per degree), for the horizontal (lines) or vertical (lines) direction as follows:

$$P_{SIR} = \frac{D_P}{2 \times n_r} \tag{16}$$

where

$D_P$    is the pixel angular density (pixel per degree) in the horizontal or vertical direction, as specified in IEC 63145-20-10.

e) Repeat the calculation of the luminance modulation at other measuring points, and then determine the static image resolution, $P_{SIR,}$ values at those positions for both horizontal (lines) and vertical (lines) directions.

### 8.3.3.5  Report

The following information shall be noted in the report:

– measuring points positions;

– pixel number of the width of the white and black lines for both horizontal or vertical lines;

– applied luminance modulation threshold ($C_T$);

– pixel angular density (pixel per degree) in the horizontal or vertical direction;

– static image resolution in both horizontal and vertical directions.

### 8.3.4  Secondary image effect

#### 8.3.4.1  General

The purpose of this method is to measure secondary images originating from undesired reflections, or transmissions of optical surfaces within the AR type eyewear displays, such as optical lenses, prisms. A secondary image refers to a spurious or ghost image, in addition to the bright primary image. The measurement should be made with the DUT luminance adjusted such that the secondary images can be seen against a dark ambient background. Subclause 8.3.4 only measures the secondary image. The measurement method is applicable when the secondary image is visible.

NOTE 1   Additional images can also affect the image quality.

NOTE 2   The AR type eyewear display can contain multiple reflection or transmission superimposed ghost images. In this document, only the secondary image which is the brightest of these ghost images is considered.

#### 8.3.4.2  Measuring conditions

The following measuring conditions apply:

a) Setup: as specified in 5.2.

b) Test pattern: a white crosshair pattern with black background is applied. The crosshair lines are $n$ pixels wide and $m$ pixels long ($n$ and $m$ are specified by the manufacturer and the supplier).

NOTE   $n$ pixels are used for better averaging of the luminance and determination of the crosshair position by 2D imaging luminance meter.

c) Light measuring devices (LMDs): a 2D imaging luminance meter can be applied to measure the luminance profiles for both secondary image and primary image. The LMD detector should have at least 5 times the line width pixels of the test pattern.

d) Measuring points: it should be specified by the manufacturer or supplier, or specified as an example of 9 points as shown in Figure 7. $H$ and $V$ represent the horizontal and vertical angles of the FOV for the virtual image.

e) Background condition: a dark room.
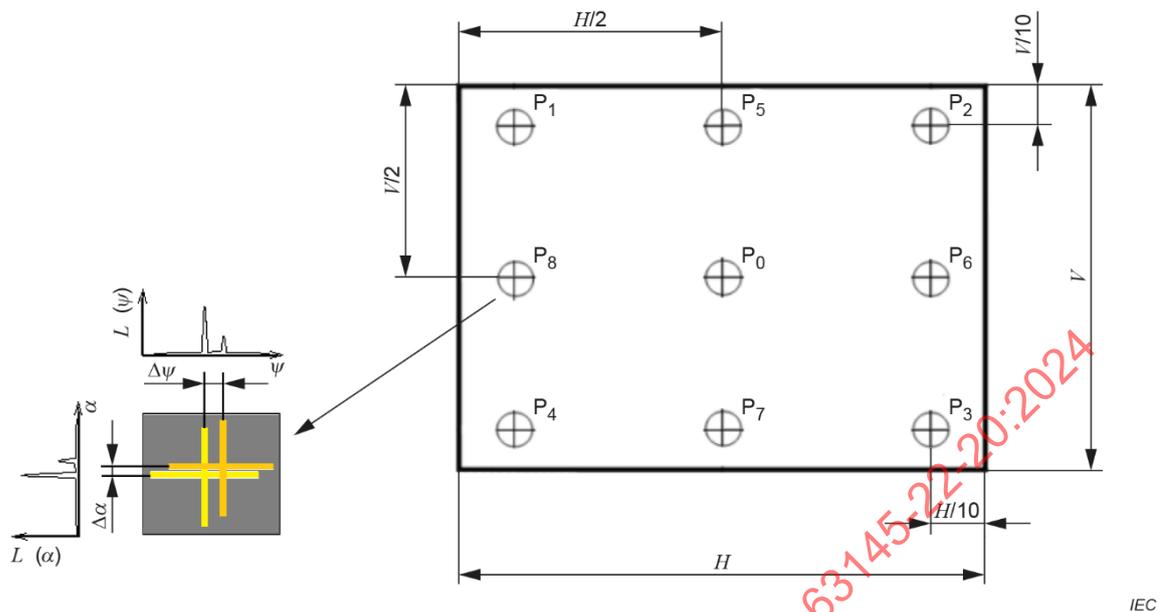
NOTE   Crosshair pattern is used to determine the relative intensity and the location of the secondary image.

**Figure 7 – Example of a secondary image**

### 8.3.4.3   Measuring procedures

Use $n$ pixels ($n$ specified by the manufacturer and the supplier) for averaging the luminance and determination of the position by 2D luminance meter.

a)   Apply a crosshair pattern at the point $P_i$ ($i$ = 0 to 8).

b)   Align the LMD with the direction at the point $P_i$ ($i$ = 0 to 8).

c)   The LMD focus is adjusted to focus on the primary crosshair image, to capture the luminance image of the primary crosshair and the secondary crosshair at the point $P_i$ ($i$ = 0 to 8).

d)   Repeat the measurements for other points $P_i$ ($i$ = 0 to 8).

### 8.3.4.4   Calculation

a)   Calculate the peak luminance $L_{pr}(\alpha, i)$ ($i$ = 0 to 8) of the primary image, and the peak luminance $L_{se}(\alpha, i)$ ($i$ = 0 to 8) of the secondary image by means of averaging pixel luminance in the azimuth, as shown in Figure 7.

b)   Calculate the peak luminance $L_{pr}(\Psi, i)$ ($i$ = 0 to 8) of the primary image, and the peak luminance $L_{se}(\Psi, i)$ ($i$ = 0 to 8) of the secondary image by means of averaging pixel luminance in the elevation, as shown in Figure 7.

c)   The luminance ratio, $LR(i)$, of the secondary image at the point $P_i$ ($i$ = 0 to 8) is calculated as follows.

$$LR(i) = \frac{L_{se}(\alpha, i) + L_{se}(\Psi, i)}{L_{pr}(\alpha, i) + L_{pr}(\Psi, i)} \tag{17}$$

where

$L_{pr}(\alpha, i)$, $L_{pr}(\Psi, i)$   are the peak luminance of the primary image in the azimuth and elevation respectively;

$L_{se}(\alpha, i)$, $L_{se}(\Psi, i)$   are the peak luminance of the secondary image in the azimuth and elevation respectively.

d) Calculate the elevation deviation $\Delta\alpha(i)$ ($\Delta\alpha(i) = | \alpha_{pr}(i) - \alpha_{se}(i) |$ ) of the peak luminance for the secondary image apart from the primary image, and the azimuth deviation $\Delta\Psi(i)$ ($\Delta\Psi(i) = |\Psi_{pr}(i) - \Psi_{se}(i)|$) of the peak luminance for the secondary image apart from the primary image at the point $P_i$ ($i$ = 0 to 8).

### 8.3.4.5    Report

The following information shall be noted in the report:

– positions of the measuring points;

– pixel number of the width of the crosshair lines;

– light measuring device (LMD);

– the luminance ratio, $LR(i)$, of a secondary image at the point $P_i$ ($i$ = 0 to 8);

– the location of the secondary image with the elevation deviation $\Delta\alpha(i)$ and azimuth deviation $\Delta\Psi(i)$ at the point $P_i$ ($i$ = 0 to 8) relative to the primary image.

### 8.3.5    Flicker

#### 8.3.5.1    General

The purpose of this method is to determine the temporal luminance modulation of the virtual image for AR type eyewear displays. Subclause 8.3.5 focuses only on the flicker caused by the AR type.

NOTE   This document excludes the effects from networks, sensors, and additional signal processors.

#### 8.3.5.2    Measuring conditions

The following measuring conditions apply:

a) Setup: as specified in 5.2.

b) Apparatus: an LMD with the following characteristics to record the temporal luminance wave as a function of time:

  • CIE photopic vision spectral response,

  • capable of producing a linear response to rapid changes in luminance,

  • frequency response: higher than 1 kHz,

  • field angle of measurement: less than 5°,

  • the LMD shall be dark field (zero) corrected.

c) Ambient condition: dark-room illumination;

d) Measuring points: the centre point (1 point) or the multi-point (5 points or 9 points) measurements are applied, and they shall be specified by the manufacturer or the supplier.

e) Test patterns: full screen solid white and colour patterns as shown in 7.3.

#### 8.3.5.3    Measuring procedure

Proceed as follows:

a) Set the DUT under the standard measuring conditions.

b) Apply the test pattern.

c) Measure the luminance as a function of time $L(t)$ at the centre of the measurement area, using the LMD.
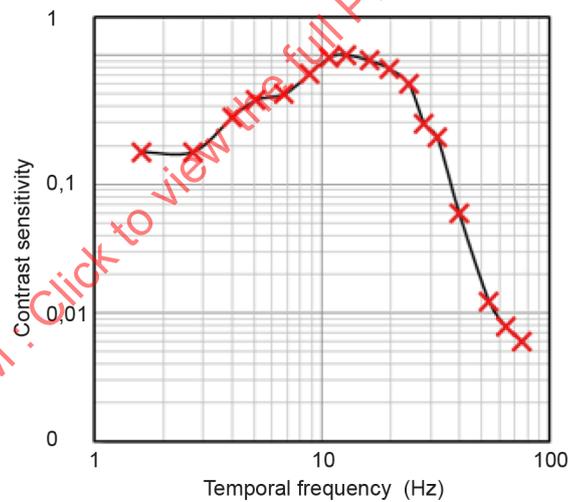
#### 8.3.5.4    Flicker calculation

Proceed as follows:

a) Perform a Fourier transform with the array of data $L(t)$, to acquire the power spectrum $P(F)$.

b) Weight the power spectrum $P(F)$ with the temporal contrast sensitivity function ($T_{CSF}$) (see Figure 8 and Table 2, to obtain the perceptive power spectrum $P'(F)$).

c) Transform $P'(F)$ to the luminance as a function of time $L'(t)$ with the inverse Fourier transform.

**Table 2 – Temporal contrast sensitivity function**

| Frequency (Hz) | Contrast sensitivity (%) | Frequency (Hz) | Contrast sensitivity (%) |
|---|---|---|---|
| 1,6 | 17,8 | 19,8 | 78,8 |
| 2,7 | 17,9 | 24 | 59,8 |
| 4,0 | 32,9 | 28 | 29,9 |
| 5,1 | 45,3 | 32 | 23,0 |
| 6,8 | 50,3 | 40 | 5,89 |
| 8,8 | 72,5 | 54 | 1,23 |
| 10,7 | 96,7 | 64 | 0,79 |
| 12,7 | 101,5 | 75 | 0,60 |
| 16,2 | 91,3 | | |



**Figure 8 – Temporal contrast sensitivity function**

d) Subsequently, calculate the flicker modulation amplitude $A_{FM}$:

1) Determine the main flicker frequency $f_M$ from the maximum of $P'(F)$.

2) Determine the flicker modulation amplitude $A_{FM}$ in per cent from $L'(t)$ as follows:

   i) obtain the average luminance, $L'_{ave}$, the maximum luminance $L'_{max}$, and the minimum luminance $L'_{min}$ of $L'(t)$;

ii)  calculate $A_\text{FM}$ as follows:

$$A_\text{FM} = \left( \frac{L'_\text{max} - L'_\text{min}}{L'_\text{ave}} \right) \times 100 \tag{18}$$

where

$A_\text{FM}$    is the flicker modulation amplitude, expressed in per cent.

### 8.3.5.5    Report

The following information shall be noted in the measurement report:

–  measuring point position;

–  test pattern;

–  temporal CSF used for filtering the recorded luminance;

–  minimum luminance ($L'_\text{min}$), maximum luminance ($L'_\text{max}$), and average luminance ($L'_\text{ave}$) of the filtered temporal luminance [$L'(t)$];

–  flicker modulation amplitude ($A_\text{FM}$), and its main modulation frequency $f_\text{M}$.

### 8.4    Parameters related to see-through real scene

### 8.4.1    See-through FOV

### 8.4.1.1    General

The purpose of the method is to measure the FOV of the real scene which can be seen through AR type eyewear displays, which could be shadowed by DUT devices, such as the glass frame, the edges of the optical combiner. The criteria are based on luminous transmittance, chromaticity, and Michelson contrast, which shall be specified by the manufacturer or the supplier.

The outer boundary of the see-through FOV can be determined according to the DUT outer frame size and design eye point provided by the manufacturer or the supplier.; The shadowed area within the outer boundary FOV can be determined by the following measurement method.

### 8.4.1.2    Measuring conditions

a)  Setup: the conditions in 5.2.3 and 5.2.4 shall be applied.

b)  Ambient background: the full-field background as in 6.2 shall be applied for the criteria based on luminous transmittance and chromaticity.

c)  Real test targets: the raster pattern targets as in 6.3 shall be applied for the criteria based on Michelson contrast.

d)  Light measuring devices (LMDs): the requirements in IEC 63145-20-10 shall apply. The entrance pupil of the luminance meter is set at the eye point of the DUT. In the case of a larger see-through FOV, the pivoting point of the LMD which is at 10 mm behind the entrance pupil can be used, instead of the pivoting point to match the entrance pupil of the LMD.

NOTE    The real target for Michelson contrast is either physically made or is a display that meets the minimum Nyquist frequency such that there are no image artifacts which occur.

### 8.4.1.3    Measuring procedures

a)  For the see-through FOV with the criteria based on luminous transmittance, the measurement shall be performed as follows.

1)  Set the ambient background to cover the whole see-through FOV of the DUT and adjust the entrance pupil of the LMD to match with the eye point of the DUT. The LMD is adjusted to focus on the virtual image distance. The DUT is applied with the full black pattern.

2) Set the rotation centre of the biaxial goniometer at the entrance pupil of the LMD or 10 mm behind the entrance pupil, then align the measurement direction with the optical axis of the DUT and measure the luminous transmittance at the centre as in 8.2.

3) Turn the LMD in the azimuth from the centre toward the left or right end of the outer boundary horizontally (keep the elevation angle, $\alpha$ = 0), and measure the luminous transmittance step by step at intervals of a given angle provided by the manufacturer or the supplier. Record the luminous transmittance, $T(i_L)$ and $T(i_R)$, at each horizontal angle, $\Psi(i_L)$ and $\Psi(i_R)$.

4) Turn the LMD in the elevation from the centre toward the top or bottom vertically (keep the azimuth angle, $\Psi$ = 0), and measure the luminous transmittance step by step at intervals of a given angle provided by the manufacturer or the supplier. Record the luminous transmittance, $T(i_T)$ and $T(i_B)$, at each vertical angle, $\alpha(i_T)$ and $\alpha(i_B)$.

5) Turn the LMD both in the azimuth and elevation from the centre toward the top-left corner, bottom-right corner, top-right corner or bottom-left corner in the diagonal direction, and measure the luminous transmittance step by step at intervals of a given angle provided by the manufacturer or the supplier. Record the luminous transmittance, $T(i_{TL})$ and $T(i_{BR})$, $T(i_{TR})$ and $T(i_{BL})$, at each horizontal and vertical angles for each direction, ($\Psi(i_{TL})$, $\alpha(i_{TL})$) and ($\Psi(i_{BR})$, $\alpha(i_{BR})$), as well as ($\Psi(i_{TR})$, $\alpha(i_{TR})$) and ($\Psi(i_{BL})$, $\alpha(i_{BL})$).

6) If necessary, turn the LMD in the other directions from the centre toward the outer boundary, and measure the luminous transmittance at each horizontal and vertical angles step by step.

b) For the see-through FOV with the criteria based on chromaticity, the measurement shall be performed as specified in the above method to measure the chromaticity from the centre toward the outer boundary and to calculate the DUT see-through FOV with the chromaticity criteria, instead of the luminance.

c) For the see-through FOV with the criteria based on the Michelson contrast, the measurement shall be performed at the angles from centre to the outer boundary of the see-through FOV as follows.

1) Set the real test target as in 6.3 at a distance provided by the manufacturer or the supplier (if not, the virtual image distance can be applied), and adjust the entrance pupil of the 2D imaging LMD to match with the eye point of the DUT (see Figure 4).

2) Adjust the LMD to focus on the centre of the see-through real test target. The centre normal of the test target is aligned with the optical axis of the LMD.

3) Measure the luminance profile of the raster real target without the DUT, and then calculate the Michelson contrast of direct viewing in accordance with the formula in IEC 63145-20-20:2019, 6.5.3.

4) Mount the DUT on the biaxial goniometer, keeping the LMD and real test target stationary. Adjust the rotation centre of the biaxial goniometer at the entrance pupil of the LMD or 10 mm behind the entrance pupil.

5) Align the optical axis of the DUT to coincide with the measurement direction of the LMD, measure the luminance profile and calculate the Michelson contrast in accordance with the formula in IEC 63145-20-20:2019, 6.5.3, with the correction of the Michelson contrast of direct viewing.

6) Rotate the DUT to align the direction of the 2D imaging LMD from the centre toward the outer boundary (edges and corners) of the DUT see-through FOV using the biaxial goniometer. The rotation directions are same as those specified in the above method with the luminance criteria, then measure the luminance profiles at each angle and calculate the Michelson contrast step by step at intervals of a given angle provided by the manufacturer or the supplier in all directions.

7) Repeat for the other ocular, if applicable.

An example of the DUT see-through FOV is shown in Figure 9 based on the Michelson contrast measurement.
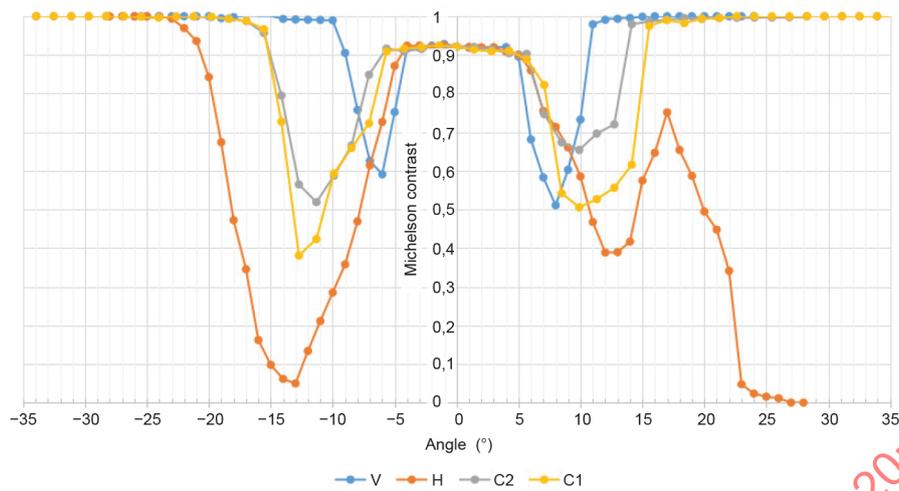
**Figure 9 – Example of the see-through FOV**

In Figure 9, "V" represents the vertical direction measurement, and "H" represents the horizontal direction measurement, "C2", and "C1" are the diagonal measurements from top left corner to bottom right corner, and top right corner to bottom left corner, respectively.

NOTE   The see-through FOV with criteria based on luminance or chromaticity uses the DUT rotating method.

### 8.4.1.4   Calculation

The angles of the horizontal FOV $A_h$ and vertical FOV $A_v$, the angles of the diagonal FOV $A_{d1}$ from top-left to bottom-right and diagonal FOV $A_{d2}$ from top-right to bottom-left, and averaged angle of the diagonal FOV $A_d$ shall be calculated as specified in IEC 63145-20-10:2019, 6.7.3, to determine the boundary of the see-through FOV and the shadowed area if applicable.

### 8.4.1.5   Report

The following information for the boundary of the see-through FOV, and the shadowed area within the whole FOV (if applicable), respectively, shall be reported:

–   angles of the horizontal see-through FOV $A_h$ and vertical see-through FOV $A_v$;

–   averaged angle of the diagonal see-through FOV $A_d$;

–   angles of the diagonal see-through FOV $A_{d1}$ from top-left to bottom-right and diagonal FOV $A_{d2}$ from top-right to bottom-left;

–   direction of the four corners $(\Psi_{TL}, \alpha_{TL})$, $(\Psi_{BR}, \alpha_{BR})$, $(\Psi_{TR}, \alpha_{TR})$ and $(\Psi_{BL}, \alpha_{BL})$;

–   direction of the four edges $(\Psi_L, \alpha_L)$, $(\Psi_R, \alpha_R)$, $(\Psi_T, \alpha_T)$ and $(\Psi_B, \alpha_B)$;

–   if a shadowed area exists, report the outer boundaries of the shadowed area;

–   if the boundaries of the FOV are not found, report the range of FOV angles in the measurement that is more than that of the measurement of the FOV range;

–   type of criteria (Michelson contrast, luminous transmittance or chromaticity) and criteria limit;

–   condition of real test target when Michelson contrast is used (angular period, scene distance);

–   eye point (eye relief), and the position of the $z$-axis;

–   type of LMD, pivoting point, and entrance pupil size;

–   ambient background illumination as the luminance level and the illuminant (relative spectral power distribution);

- accuracy of sample stage; and

- correction methods for the measurement, if possible.

### 8.4.2 Variations in luminance and chromaticity of see-through real scenes

#### 8.4.2.1 General

The purpose of this method is to measure the variations in luminance and chromaticity of the real scene in the background at different orientations of an AR type eyewear display. The see-through FOV of the DUT shall be provided by the manufacturer or supplier. The luminance and relative spectral power distribution as CIE Illuminant A, D65, D50, etc., for the scene background, shall be specified by the manufacturer or supplier. If not, then 150 cd m$^{-2}$ and CIE Illuminant A (2 856 K) for indoor applications, and 1 500 cd m$^{-2}$ and CIE Illuminant D65 (6 500 K) for outdoor applications can be applied.

#### 8.4.2.2 Measuring conditions

a) Setup: the conditions in 5.2.3 and 5.2.4 shall be applied.

b) Uniform source target: an integrating sphere or a flat source with uniform light output as specified in 6.2 shall be applied. The dimension (or subtense angle at a measurement distance) of the uniform source should be specified by the manufacturer or supplier.

c) Light measuring devices (LMDs): a spectral radiance meter shall be applied. The meter shall be focused on a distance which is provided by the manufacturer or supplier. If the distance is not provided, then the distance of the virtual image can be applied. The requirements in IEC 63145-20-10 shall be referred to. The entrance pupil of the LMD shall be set at the eye point of the DUT.

d) Measuring points: the locations of measuring points in Figure 10 can be applied, while $A_h$ and $A_v$ are the horizontal size and vertical size of the real scene FOV, respectively.
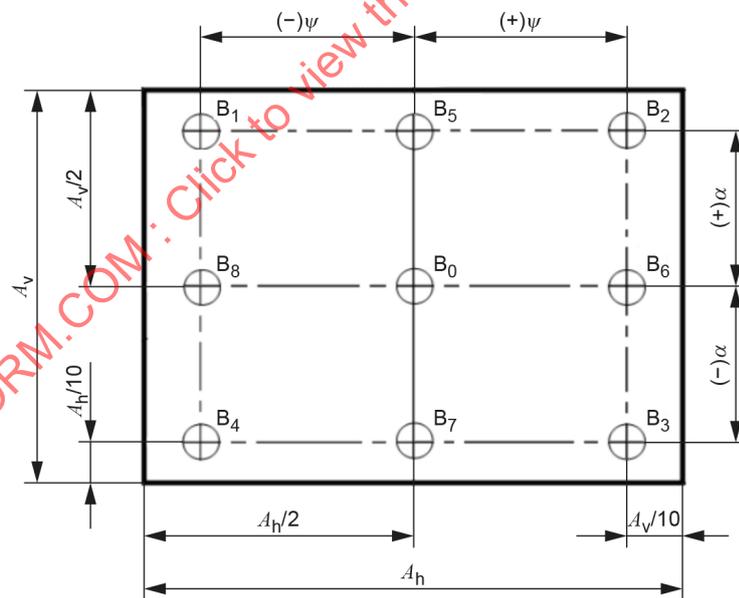


**Figure 10 – Measuring points of the real scene (origin at the centre B$_0$, corresponding to the optical axis of the DUT)**

### 8.4.2.3 Measuring procedures

a) Set the DUT and turn off the virtual image of the DUT.

b) Set the uniform source target at the real scene distance and turn it on until it is stable in the light output.

c) Align the LMD perpendicular to the centre of the uniform source target.

d) Pivot the LMD together with the source target, or the DUT at the eye point, towards point $B_i$ ($i$ = 0 to 8) in the direction ($\Psi_i$, $\alpha_i$) as shown in Figure 10.

e) Measure the spectral radiance of the uniform source target at point $B_i$ in the see-through condition, $L_{Amb,DUT}(\lambda, i)$.

f) Repeat d) to e) for the measurements of other points.

g) Remove the DUT, and then directly measure the spectral radiance of the uniform source target, $L_{Amb,0}(\lambda)$.

h) The spectral transmittance $T(\lambda, i)$ at the point $B_i$ ($i$ = 0 to 8) for the DUT can be obtained by the formula $T(\lambda, i) = L_{Amb,DUT}(\lambda, i) / L_{Amb,0}(\lambda)$.

i) For a binocular AR type eyewear display, repeat steps a) to h) to determine the spectral transmittance of another ocular, if applicable.

### 8.4.2.4 Calculation

a) The luminance Level $L_s$ and relative spectral distribution $S(\lambda)$ of the real scene target shall be provided by the manufacturer or supplier.

NOTE   CIE Illuminant A, D65 or D50 is usually used for the relative spectral distribution, $S(\lambda)$, (refer to 8.4.2.1).

b) The percentage variation of luminance of the see-through real scene, i.e. luminous transmittance of the DUT for the real scene target, can be determined as follows.

1) The luminance of the see-through real scene at the point $B_i$ ($i$ = 0 to 8) is calculated as follows:

$$L(i) = 683 \cdot \sum_{380}^{780} T(\lambda, i) \cdot L_S(\lambda) \cdot V(\lambda) \cdot \Delta\lambda \tag{19}$$

where

$L(i)$ is the luminance of the see-through real scene at the point $B_i$ ($i$ = 0 to 8);

$L_s(\lambda)$ is the spectral radiance distribution of the real scene illumination;

$V(\lambda)$ is the CIE standard spectral luminous efficiency function for photopic vision;

$\Delta\lambda$ is the spectral interval of the calculation.

$$L_S(\lambda) = \frac{L_S \cdot S(\lambda)}{683 \cdot \sum_{380}^{780} S(\lambda) \cdot V(\lambda) \cdot \Delta\lambda} \tag{20}$$

2) The luminous transmittance (percentage variation of luminance) at the point $B_i$ ($i$ = 0 to 8) is calculated as follows:

$$C_L(i) = \frac{L(i)}{L_s} \cdot 100 \tag{21}$$

where

$C_L(i)$      is the luminous transmittance at the point B$_i$ ($i$ = 0 to 8), expressed in per cent.

3) The averaged luminous transmittance of the real scene in the see-through condition, $C_{av}$, is calculated as follows.

$$C_{av} = \frac{1}{9}\sum_{i=0}^{8} C_L(i) \tag{22}$$

c) Chromaticity deviation is determined as follows.

1) The chromaticity coordinates, $x(i)$, $y(i)$ and $z(i)$ (i.e. 1 - $x(i)$ - $y(i)$) of the real scene at point B$_i$ ($i$ = 0 to 8) in the see-through condition, can be calculated as follows:

$$x(i) = \frac{X(i)}{X(i)+Y(i)+Z(i)}$$
$$y(i) = \frac{Y(i)}{X(i)+Y(i)+Z(i)} \tag{23}$$

$$X(i) = 683 \cdot \sum_{380}^{780} T(\lambda,i) \cdot L_s(\lambda) \cdot \overline{x}(\lambda) \cdot \Delta\lambda$$
$$Y(i) = 683 \cdot \sum_{380}^{780} T(\lambda,i) \cdot L_s(\lambda) \cdot \overline{y}(\lambda) \cdot \Delta\lambda \tag{24}$$
$$Z(i) = 683 \cdot \sum_{380}^{780} T(\lambda,i) \cdot L_s(\lambda) \cdot \overline{z}(\lambda) \cdot \Delta\lambda$$

where

$X(i)$, $Y(i)$, $Z(i)$      are the tristimulus values of CIE 1931 of the real scene at the point B$_i$ ($i$ = 0 to 8);

$\overline{x}(\lambda)$, $\overline{y}(\lambda)$, $\overline{z}(\lambda)$      are the CIE colour-matching functions adapted by CIE 1931 (see ISO/CIE 11664-1).

2) The CIE 1976 chromaticity coordinates $u'(i)$, $v'(i)$ are calculated from the CIE 1931 chromaticity coordinates $x(i)$, $y(i)$ (see ISO/CIE 11664-5).

$$u'(i) = \frac{4x(i)}{-2x(i)+12y(i)+3}$$
$$v'(i) = \frac{9y(i)}{-2x(i)+12y(i)+3} \tag{25}$$

where

$u'(i)$, $v'(i)$      are the CIE 1976 chromaticity coordinates of the real scene target with the DUT at the point B$_i$ ($i$ = 0 to 8).

3) The CIE 1976 chromaticity coordinates of the real scene target without the DUT, $u'_o(i)$, $v'_o(i)$, at each point B$_i$ ($i$ = 0 to 8) are calculated using analogous relations to Formula (23), Formula (25) and the following formula:

$$X_o(i) = 683 \cdot \sum_{380}^{780} L_s(\lambda) \cdot \overline{x}(\lambda) \cdot \Delta\lambda$$

$$Y_o(i) = 683 \cdot \sum_{380}^{780} L_s(\lambda) \cdot \overline{y}(\lambda) \cdot \Delta\lambda \tag{26}$$

$$Z_o(i) = 683 \cdot \sum_{380}^{780} L_s(\lambda) \cdot \overline{z}(\lambda) \cdot \Delta\lambda$$

where

$X_o(i)$, $Y_o(i)$, $Z_o(i)$   are the tristimulus values of CIE 1931 of the real scene target without the DUT at the point $B_i$ ($i$ = 0 to 8).

4) Use the CIE 1976 chromaticity coordinates $u'(i)$, $v'(i)$ at each point $B_i$ ($i$ = 0 to 8) to determine the chromaticity deviation using the following formula.

$$\Delta u'v'(i) = \sqrt{\left(u'(i) - u'_o(i)\right)^2 + \left(v'(i) - v'_o(i)\right)^2} \tag{27}$$

where

$u'_o(i)$, $v'_o(i)$   are the CIE 1976 chromaticity coordinates of the real scene target without the DUT at the point $B_i$ ($i$ = 0 to 8).

5) The averaged chromaticity deviation is obtained as follows:

$$(\Delta u'v')_{av} = \frac{1}{9}\sum_{i=0}^{8} \Delta u'v'(i) \tag{28}$$

d)  Repeat for another ocular, if applicable.

### 8.4.2.5    Report

The following information should be reported:

– measuring points;

– luminance level and relative spectral distribution of the real scene;

– luminance of each point $B_i$, and averaged luminance variation;

– chromaticity deviation at each point $B_i$ ($i$ = 0 to 8) and  averaged chromaticity deviation;

– eye point (eye relief);

– type of LMD and the aperture size;

– dimension of the uniform source target and the measurement distance;

– accuracy of sample stage; and

– correction methods for the measurement, if necessary.

### 8.4.3    Real rectangular scene distortion

### 8.4.3.1    General

The purpose of this method is to determine the real scene distortion produced by the optics of AR type eyewear displays for a real scene. The real rectangular scene distortion is applied to

describe the position (direction) distortion of the target points appearing in the see-through scene from that in the real world.

### 8.4.3.2     Measuring conditions

The following measuring conditions apply:

a)  Stage and setup conditions: as in 5.2.3 and 5.2.4.

b)  Light measuring device (LMD): a 2D imaging meter that can capture the crosshair pattern of the real scene target. The requirements in IEC 63145-20-10 and IEC 63145-20-20 shall be referred to. The entrance pupil of the LMD is set at the eye point of the DUT. In the case of a larger see-through FOV, the pivoting point of the LMD which is located 10 mm behind the entrance pupil can be used, instead of the entrance pupil to match the eye point of the DUT.

c)  Dark room conditions: as in 4.4.

d)  Real scene target: a crosshair pattern target as in 6.4 shall be applied, for example, a recommended line width of 1/15° to 1/30°, or a line length of no more than 0,5° angle. The target illumination should avoid using polarized light, such as the crosshair pattern generated by an LCD screen.

e)  Measuring points: 9 points as shown in Figure 10 are applied. The rectangular scene FOV ($A_h$ and $A_v$) shall be provided by the manufacturer or the supplier.

### 8.4.3.3     Measuring procedures

a)  Set the crosshair pattern target at the measurement distance, which is provided by the manufacturer or the supplier (if not, the virtual image distance can be applied).

b)  Align the LMD perpendicular to the crosshair pattern target and point to the cross-point of the pattern target.

c)  Set the DUT and turn off the internal virtual image, adjust the optical axis of the DUT to be consistent with the optical axis of the LMD (i.e. the LMD points to $B_0$ of the see-through FOV).

d)  Pivot the LMD together with the crosshair target, or rotate the DUT around the pivoting point of the LMD, towards point $B_i$ ($i$ = 0 to 8) in the direction ($\Psi_i$, $\alpha_i$) as shown in Figure 10.

e)  Capture the image of the crosshair pattern target.

f)  Calculate the position deviation ($\Delta\Psi_i$, $\Delta\alpha_i$) of the cross-point in the crosshair pattern image at the point $B_i$ ($i$ = 1 to 8)

### 8.4.3.4     Calculation

The rectangular scene distortion is determined as follows:

a)  Horizontal distortion $D_h$, expressed in per cent;

$$D_h = \frac{(\Delta\Psi_2 + \Delta\Psi_3 - \Delta\Psi_1 - \Delta\Psi_4) - 2(\Delta\Psi_6 - \Delta\Psi_8)}{2(\Delta\Psi_6 + \Psi_6 - \Delta\Psi_8 - \Psi_8)} \times 100 \qquad (29)$$

b)  Vertical distortion $D_v$, expressed in per cent;

$$D_v = \frac{(\Delta\alpha_1 + \Delta\alpha_2 - \Delta\alpha_3 - \Delta\alpha_4) - 2(\Delta\alpha_5 - \Delta\alpha_7)}{2(\Delta\alpha_5 + \alpha_5 - \Delta\alpha_7 - \alpha_7)} \times 100 \qquad (30)$$

### 8.4.3.5 Report

An example of the real scene distortion is shown in Table 3. The rectangular scene FOV with $A_h$ = 40º and $A_v$ = 40º is applied in the distortion measurement.

**Table 3 – Example of the angle deviation of the 9 points and the distortions**

| Points | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ |
|---|---|---|---|---|---|---|---|---|
| $\Psi$ | −16 | 16 | 16 | −16 | 0,16 | 16 | 0 | −16 |
| $\alpha$ | 16 | 16 | −16 | −16 | 16 | 0 | −16 | −0 |
| $\Delta\Psi$ | 0,011 | 0,583 | 0,545 | 0,011 | 0,006 | 0,588 | 0,008 | 0,126 |
| $\Delta\alpha$ | −0,022 | 0,236 | 0,038 | −0,022 | −0,016 | −0,297 | −0,022 | 0,052 |
| Horizontal distortion: $D_h$ = 0,55 % | | | | | | | | |
| Vertical distortion: $D_v$ = 0,58 % | | | | | | | | |
| Unit: degree | | | | | | | | |

The following information should be reported:

– rectangular scene FOV ($A_h$ and $A_v$), and coordinates of measuring points;

– real scene target;

– position deviation ($\Delta\Psi_i$, $\Delta\alpha_i$) of each crosshair $i$, ($i$ = 0 to 8);

– horizontal distortion and vertical distortion;

– eye point (eye relief);

– type of LMD, the pivoting point, and the entrance pupil size;

– accuracy of sample stage; and

– correction methods for the measurement, if possible.

### 8.4.4 Real local geometric distortion

#### 8.4.4.1 General

The purpose of this method is to determine the local geometric distortion produced by the optics of AR type eyewear displays for a real scene. This method indicates the level of displacement of a see-through image to its real position over the real scene FOV ($A_h$ and $A_v$) which is given by the manufacturer or the supplier.

#### 8.4.4.2 Measuring conditions

The following measuring conditions apply:

a) Rotating stages: a five-axis goniometer target as in 5.2.3 for mounting the LMD to perform an angular scan over the real scene, and a biaxial goniometer for mounting the DUT to achieve an equivalent angle of the eye gaze.

b) Light measuring device (LMD): a 2D imaging meter that can capture the image of the real scene target. The LMD should have at least 5 pixels in the orthogonal directions to accurately resolve the centroid of the real scene target. The entrance pupil of the LMD is set at the eye point of the DUT. In the case of a larger see-through FOV, the pivoting point of the LMD which is located 10 mm behind the entrance pupil can be used, instead of the entrance pupil to match the eye point of the DUT.

c) Dark room conditions: as in 4.4.

d) Real scene target: a crosshair target as in 6.4, or a white circular dot target on a black background shall be applied. For example, a line width of 1/15° to 1/30° and its length of no